Strawman Funding Opportunity Announcement (FOA)

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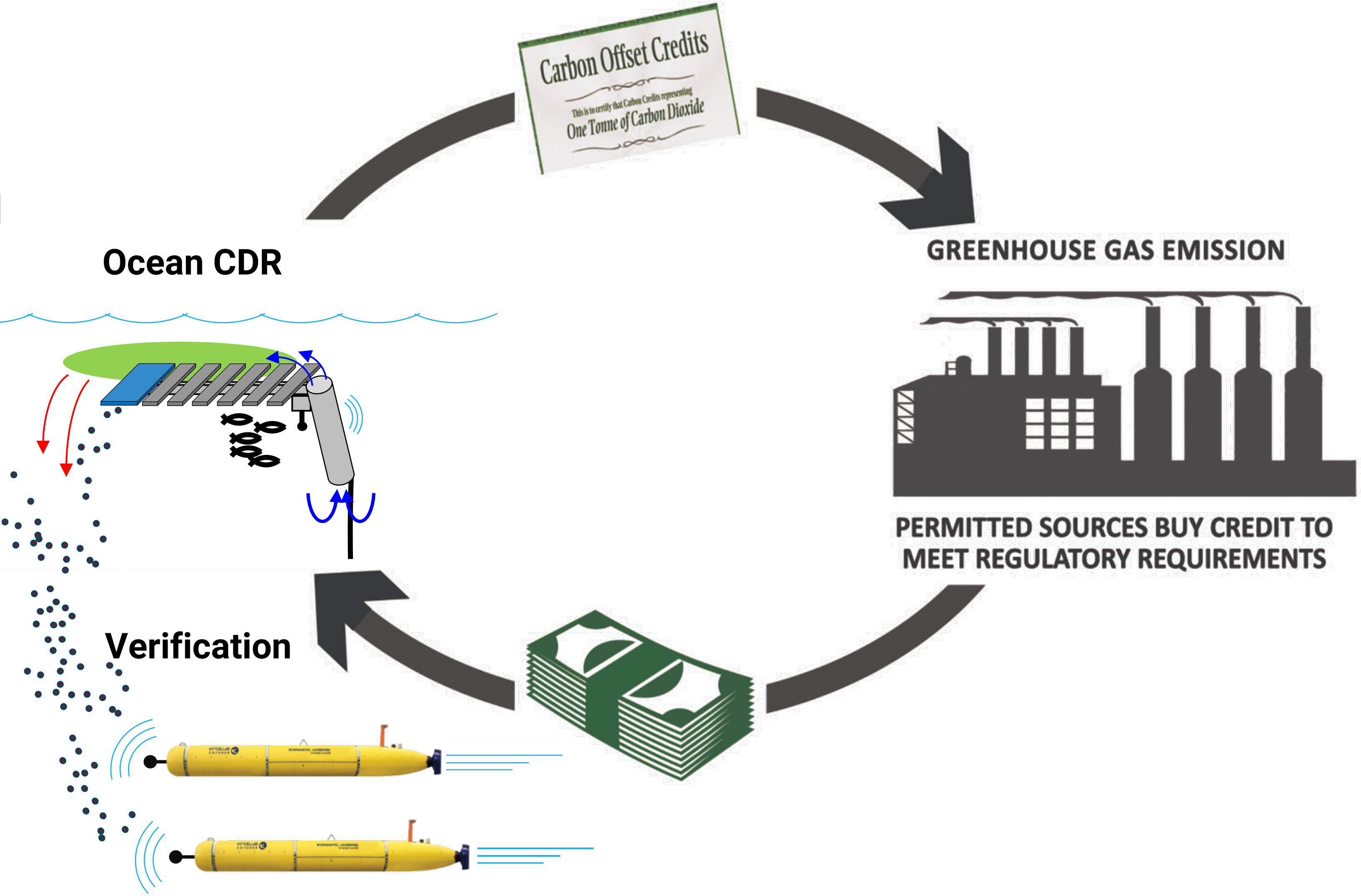
ARPA-E Goals

What are we trying to do?

Quantify the amount of carbon captured through distributed marine Carbon Dioxide Removal processes

- Develop scalable carbon sensing
- Create virtually perpetual, energy harvesting platforms
- Create effective models to estimate CDR performance



Why does this matter?

- Quantification gives marine CDR financial value in a carbon market
- Enables enormous scalability for solutions to *reversing our existential climate disaster*
- Avoids resource conflicts with terrestrial industries

Strawman FOA:

The following are present ideas for what an ARPA-E program on marine CDR MRV **might** look like. They are:

- Notional
- Fluid
- Not a promise of any future funding

We want your feedback on potential program design so as to maximize effectiveness.

We are open to feedback in the breakouts or elsewhere.

Purpose of the FOA:

A call for proposals on transformational project concepts that can:

- Enable scalable, economic and “sufficiently” constrainable sensing of ocean carbon parameters that will quantify CDR performance in a manner sufficient for carbon markets.

- Develop technologies in three areas to achieve this goal:
  1. New ocean carbon parameter sensors that transform our MRV sensing capabilities
  2. Sensor platforms capable of “persistence” through energy harvesting, that can profile the full water column
  3. Validated models that simulate CDR to a “certain” accuracy and can assimilate observational data to enhance certainty.

- Ultimately lead to demonstrations that show “economically feasible” MRV capabilities for real-world marine CDR.

“ ” – potential metrics

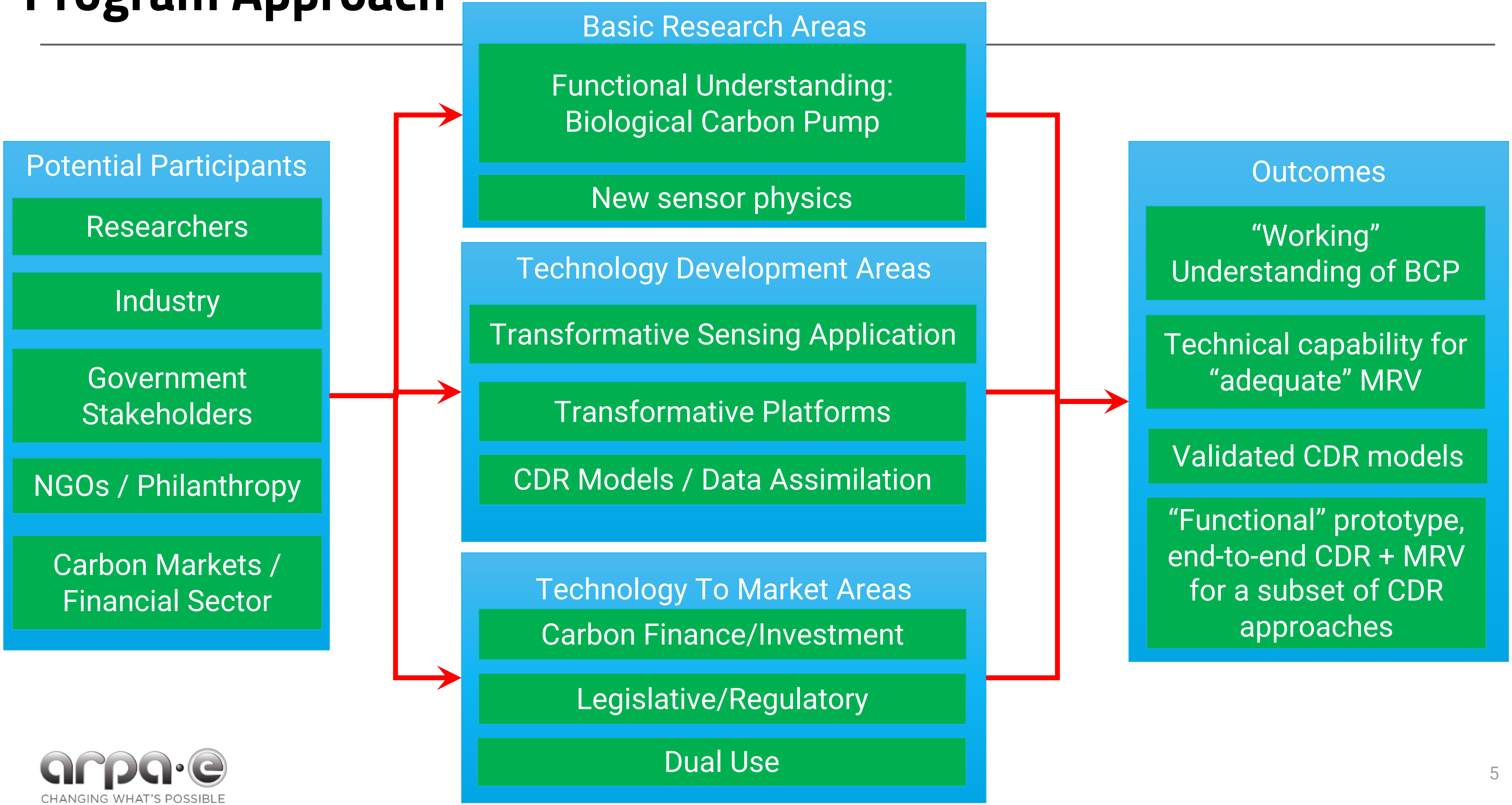
Potential Teaming Strategy

- Integrated teams:
  - Sensors
  - Platforms
  - Models
  - Technology to Market (carbon market, legislative, dual use)

Why? *Integration is more challenging, but success would provide a viable end-to-end solution so long as program metrics align with market requirements.*

- ARPA-E is looking to partner (or have teams partner) with other government agencies, NGOs, and other institutions participating in the Ocean CDR industry.

Program Approach



Partnering with Philanthropy

- Idea: partner with private CDR development efforts.
- ARPA-E will potentially fund MRV development, not CDR.
- Significant interest from NGO/Philanthropy sector in funding CDR research - emphasis on basic research, but also pilot-scale testing at sea.
- A public-private partnership where the government serves as the MRV ‘referee’ for CDR development efforts?
- This way, MRV techniques developed by the U.S. government can be:
  - Tested on real-world CDR pilot tests
  - Discussed and co-designed internally with regulatory agency participation
- Do you see any risks here? How could we mitigate them?

BYO CDR

- CDR choice up to proposers.

- Must provide evidence their choice / project arrangement will:
  - Be net carbon negative
  - Be scalable to at least "0.1 MMT (million metric tonnes)" in the 2030 timeframe, "1 MMT" in the 2040 timeframe, "1 BMT" in the 2050 timeframe
  - Offer evidence for "long-term" sequestration
  - Offer a roadmap to "economic competitiveness *including the cost of MRV*"

Including MRV costs may fundamentally change the viability of CDR techniques.

It's not just the scientific validity that governs CDR success. Market viability is the enabler of scale.

" " – potential metrics

Strawman Technical Approach

"First, but wrong. But first!" – *Kevin Heaney, Applied Ocean Sciences*

- Emphasis on early at-sea testing: first sensor/platform prototypes deployed <9 mo. From kickoff. Regular iteration/testing thereafter. *Performers will thus need regular, cost-effective access to target MRV environments*.

- Simultaneous development of the three technical areas. Integration after significant Technology Readiness Level (TRL) milestones begins at ~1/3 of program timeline.

- Initial, integrated MRV approach demonstrations required ~2/3 of the way through.

- At-sea testing and demonstration at the culmination of the program. *"Nothing like a demo to convince an admiral"*.

Tech-to-Market (Early Markets/Dual Use Examples)

- Technologies developed under this program may serve markets that already exist, providing opportunities to advance TRL or increase economies of scale—benefitting our overall mCDR MRV goals.

  - **Sensors:** Robust sensing technologies for DIC, DOC, POC, and PIC may be desirable by industry services/platforms not tied to specific mCDR MRV operations.

  - **Platforms:** Low-cost, low-power platforms that can indefinitely harvest energy in the field could be outfitted with other sensor payloads for applications in ocean observing, academic research, and national security.

  - **Modeling:** Improved sensing/modeling capabilities developed for mCDR MRV processes (e.g., oceanic transport) can be applied to other types of environmental monitoring (e.g., marine debris circulation).

Tech-to-Market (Regulatory)

- Regulations, permitting procedures, and management strategies for mCDR do not yet exist, although there is significant interest from regulatory bodies on the development of such legislation.
  - Opportunity to work with federal agencies (i.e., NOAA) to develop a MRV framework for the U.S.
  - Opportunities to work with NGOs and international partners to develop requirements and inform MRV activities internationally.

Sensor Metrics: Today and Proposed

General approach to sensor performance: Match established standards for water chemistry measurements adopted by community

	Today's Sensor Metrics	Proposed ARPA-E Sensor Metrics
1D: Distance/time	1 km/h @ 10 m/sample	**1 km/h @ 25 mm / sample (100**
2D: Area/time	N/A	**0.25 sq km/h**
3D: Volume/time	N/A	**0.125 km^3/h**
pH accuracy	0.02	**0.04**
Time required per sample	0.1s - 12 min.	100 ms
Sample distance from sensor	flow-through	10 mm - km
Operating T (C)	0 - 50	-1.9 - 50
Calibration drift time constant	eg. pH up to 0.06/yr	**inf.**
Size	~0.3 m^3	< 1000 cc
Weight	3 - 10 kg	< 1 kg
Power	0.4-10 W	**milliWatt scale**
Consumable duration	N/A to 600 measurements	N/A
Maximum Depth (m)	e.g. 50, 120, 4000 m	**6000 m**

Platform Metrics: Today and Proposed

General approach to sensor performance: Match established standards for water chemistry measurements adopted by community

	Today's platform metrics (e.g. 6000 m capable REMUS 600)	Proposed ARPA-E Platform Metrics
Endurance @ 2 kts	10 h	**Constrained by biofouling, if anything**
Procurement cost	$3M	<$100K/unit, scaled to <$20K/unit @ 1000 units
OPEX per day	$50K (takes a village, and a ship)	<$1K/day (i.e., one remote operator for entire network)
Size	4 m, 12" dia.	< 2 m length (transportation, small boat deployment)
Weight	300 kg (crane required)	< 100 kg (2-man portable)
Energy Harvesting	NO	**YES**

Metrics: What We Are Missing

- How do we evaluate model performance?
  - Closeness of estimates to holdout data, over longer timescales
  - Computational resources required/speed
  - Sparsity of data input: Less is more.

- Potential Higher-Level Metrics for Integrated Teams
  - Constrain error on error (known unknowns)
  - MRV cost per 10-year ton, in addition to CDR cost per 10-year ton
  - MRV capital/operational expenditure and economies of scale

- What other high-level, whole-project metrics would assist with market adoption?

Breakout Discussion 4 Overview

Program Design

- Maximize the odds of transformative success
- How to manage a diversity of CDR approaches
- Metrics vs. time, high-level vs. specific.

Technology to Market: Early Markets/Dual Use

- Where else could this technology be useful?
- Who else should know about this work
- Business models

Technology to Market: Legislative

- How can metrics assist legislation?
- Goals: scaling or economics?
- Environmental impacts
- Precedent?

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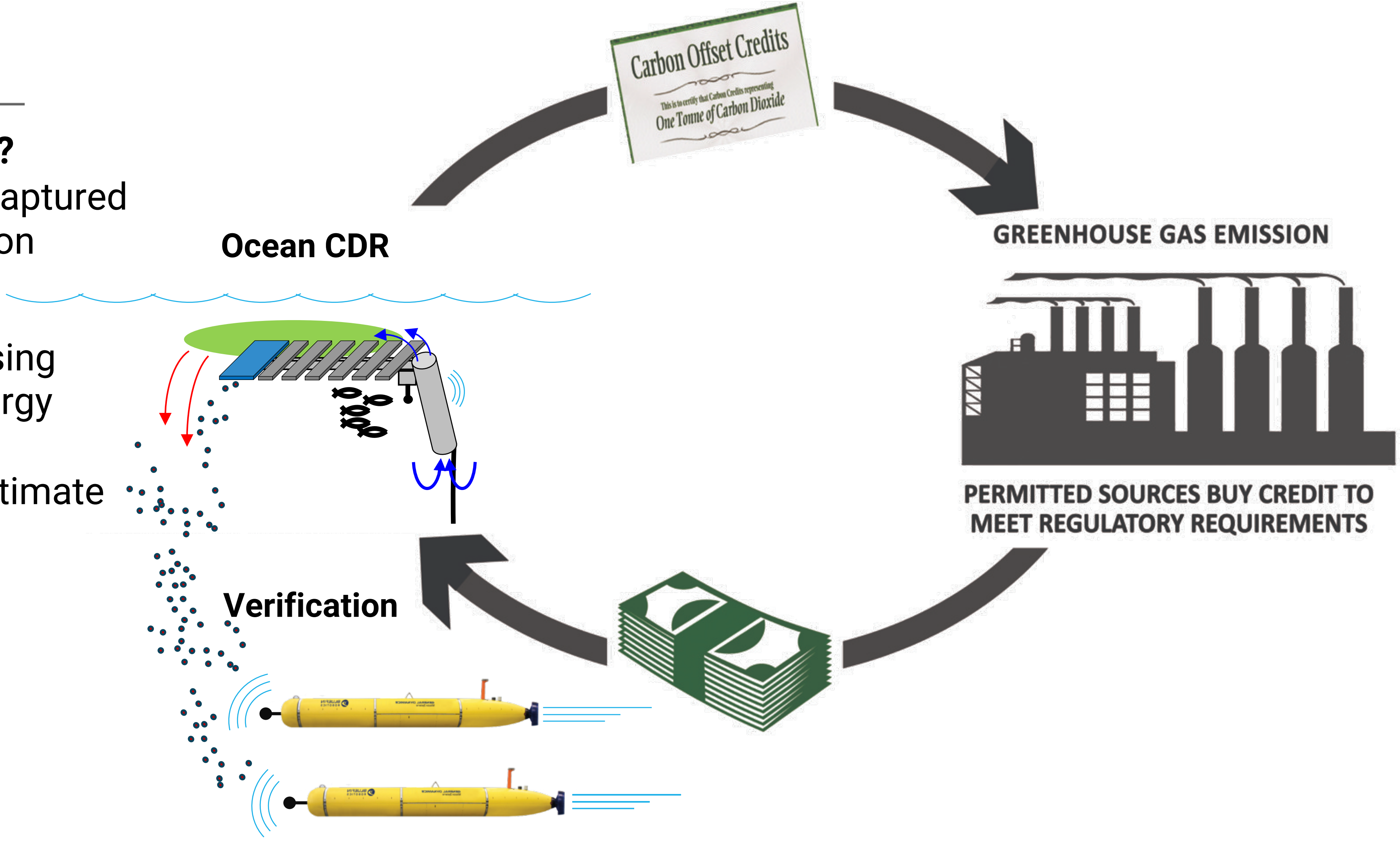

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